VOLUME 78 SEPARATE No. 148

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

SEPTEMBER, 1952

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BANK STABILIZATION BY REVETMENTS AND DIKES

By Raymond H. Haas and Harvill E. Weller

WATERWAYS DIVISION

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Printed in the United States of America

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

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Proceedings—Vol. 78 September, 1952 Separate No. 148

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

PAPERS

BANK STABILIZATION BY REVETMENTS AND DIKES

By Raymond H. Haas[1] and Harvill E. Weller[2]

Synopsis

Aggravated by wide variations of hydrographic and physiographic elements, the problem of bank stabilization on the Lower Mississippi River has been found to be extremely complex. Since the problem is primarily one of arresting bank recession, revetment is the principal type of structure employed; dikes, retards, and groins are installed to a lesser extent depending on the particular situation encountered. These bank protection structures have been developed by theory and experience since the early 1880's. For the most part, the details of their design are peculiar to the lower river alone. The protection of the banks is progressing in a systematic manner, with a view to modifying the primitve stream artificially for the purpose of securing effective flood control and navigation.

Introduction

The probem of stabilizing the Lower Mississippi River is not wholly a matter of applying known hydraulic formulas; nor is it simply a proposition of adopting structural design that has proved successful elsewhere. Details of the protective structures in use are peculiar, for the most part, to the lower river alone. These structures, revetments, dikes, groins, and retards are designed to fit conditions not only in the lower river generally, but also those conditions prevailing in a particular reach at the time they are to be used.

Instability of the River Banks.—The Lower Mississippi River, because of its wide variations in depth and width, volume and velocity, direction of flow, slope and water surface, and conditions of bed and banks presents an extremely difficult problem of stabilization. These factors all contribute to the erosion of the banks and consequent formation of bars. The river banks are inherently

Note.—Written comments are invited for publication; the last discussion should be submitted by March 1, 1953.

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unstable, being composed of finely divided clays and silts overlying easily erodible sands. Bank recession may vary from a few feet annually to more than 1,500 ft in some isolated cases. It has been computed that the caving banks between Cairo, Ill., and Donaldsonville, La., yield annually about 1,000,000 cu yd of material per mile. The silt in colloidal suspension, however, is of secondary importance since, although it has been variously estimated as being between 300,000,000 cu yd and 400,000,000 cu yd annually, it is probably transported in one continuous journey from its source to the Gulf of Mexico. The major part of the material from a caving bank forms an accretionary deposit immediately below its source. As the bank in a concave bend continues to recede, the point bar below enlarges and consequently aggravates the bank caving conditions in the next bend downstream.

Therefore, the basic difficulty to be overcome by bank stabilization on the Lower Mississippi River is the instability of the river itself.

History of Bank Stabilization Efforts.—Prior to the creation of the Mississippi River Commission (hereinafter called the "Commission") in 1879, a board of engineers concluded that the greatest obstacle to navigation improvement and levee maintenance was bank caving. In its first preliminary report, submitted in 1880, the Commission called for navigation improvement by regulation of the river channel and by protection of its banks.[3] The improvement was to be accomplished by the construction of permeable contraction works that would limit the width of the low-water channel to 3,000 ft, and by bank revetments that would arrest recession in the concave bends. Late in 1881 the Commission initiated operations for the stabilization of Plum Point reach, about 130 miles above Memphis, Tenn., and in the Lake Providence reach in northern Louisiana. It was not until the passage of the Flood Control Act of December 22, 1944, which authorized completion of the stabilization program on the Lower Mississippi River, that adequate funds, plants, and equipment were made available to prosecute the work in a systematic manner. As planned, bank revetment will be the principal structure in the program because the problem is mainly one of arresting bank recession in concave bends in which depths are too great for any other known device to be constructed economically. Dikes, retards, and groins will be used where feasible, to prevent bank caving, but to a greater extent for supplementary works.

Revetments

Design of Revetments.—A revetment is a structure designed to protect the river banks directly. It consists of two distinct parts: The section below normal low water, known as the "mattress," and the part extending from the mattress to the top of bank, called "bank paving." The mattress work comprises roughly three fourths to four fifths of the entire structure.

Experience has shown that, to be effective, a revetment must be sufficiently long to protect the entire concave bend from the upper to the lowermost points of caving at all stages. It must extend from the top of the bank to the toe of the underwater slope, a vertical distance of from 80 ft to 150 ft. It should

[3] "Annual Report of the Chief of Engineers 1880," Appendix SS, pp. 2733–2736, U. S. Govt. Printing Office, Washington, D. C.

be flexible so that it can mold itself to irregular surfaces; it must have sufficient strength to remain intact in the event of uneven slope settlement or scour. It should be relatively impermeable and continuous in order to prevent fine soil particles from leaching out through the mattress under the action of current that may reach a maximum velocity of 12 ft per sec. Also, as far as practicable, the revetment material should be indestructible in air or water.

Construction.—Construction normally follows a sequence of bank clearing and grubbing, clearing of the underwater slope of snags, bank grading, mattress sinking, and, finally, bank paving.

The bank in a concave bend is typically very steep above the water surface and, consequently, is unstable. Therefore, grading to a stable slope, initially, is necessary. The slope required for stability is determined by an analysis of the soil from representative borings taken at close intervals along the bank on which the revetment is to be constructed. Bank slopes varying between the limits of 1 ft vertical to from 3 ft to 5 ft horizontal are usually required to insure stability.

In the earlier days of construction, banks were usually graded after the sinking of the subaqueous mattresses; but the availability of equipment to do this part of the work, without delaying progress on the work as a whole, was often the determining factor. Usually the bank was graded after the mattress was in place because it was thought that the waste material from the bank-grading operations was beneficial for filling or loading the mattress. Bank-grading operations today are prosecuted in advance of sinking operations because of operational considerations and because the modern mattress has sufficient body and weight to eliminate the requirement for filling and loading.

Development of Materials.—Soon after the initiation of work by the Commission at Plum Point and Lake Providence, it became apparent that the light, flexible, and comparatively inexpensive structures of poles and brush being used were inadequate to cope with the conditions prevailing on the lower river. Between 1882 and 1893 numerous mattress types of willow, lumber, and other native materials were designed and tested. Two of the types developed during this period, the framed willow and willow fascine mattresses, were used extensively until about 1930. Because of the scarcity of willows, the short construction season, the relatively slow production rate, and the greater cost of construction only a limited number of these types of revetments have been constructed since 1930. The most recent examples of the use of these types were a willow fascine mattress placed in Memphis harbor in 1948, and a framed willow mattress constructed in New Orleans (La.) harbor in 1949.

Articulated Concrete Mattress.—During the thirty-year period between 1914 and 1944, four distinct types of concrete mattresses and one compacted asphalt mattress were developed. Of these types (the monolithic concrete, the articulated concrete, the lapped and butt slab, the compacted asphalt, and the flexible roll type concrete) only the articulated concrete mattress proved to be satisfactory in respect to production, cost, and service.

The articulated concrete mattress originated with experiments, begun in 1915, to develop a flexible and permanent underwater mattress. After many trials and alterations, the present forms of mattress and sinking mechanism

were evolved. The mattress is composed of precast units 25 ft long by 4 ft wide and 3 in. thick. Each unit has twenty individual blocks, 14 in. wide, spaced approximately 1 in. apart, on heavy corrosion-resisting reinforcing fabric that is continuous throughout the unit. The precast units are assembled on the sloping deck of a launching barge where they are united to each other and to launching cables by wire rope clips and twist wires. The launching cables are fastened ashore to anchors embedded in the bank. The barge is then moved riverward 25 ft, allowing the joined units to slide off the curved launching apron and hang suspended in the water on the launching cables. This launching process is repeated until a complete mattress of any desired width has been constructed. The cables are then cut at the outstream end and the plant moved upstream into position for laying the next mattress. Details of the placement operation are shown in Figs. 1 and 2.

The articulated concrete mattress is the best type of revetment devised, and the only type that can be placed at the rate required for the proper prosecution of the stabilization program. Three complete revetment construction plants, especially designed to place the articulated concrete mattress, are

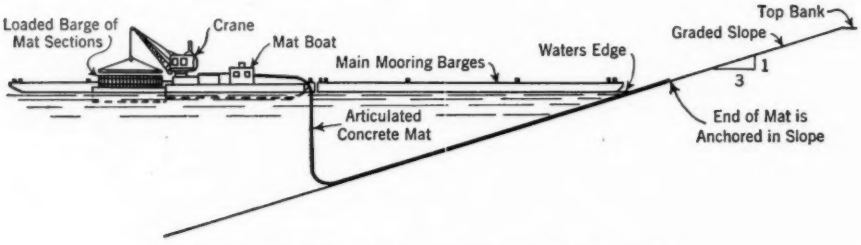

FIG. 1.—PLACEMENT OF ARTICULATED CONCRETE MATTRESS

operating in the lower river. The normal combined capacity of these three plants is 140,000 squares (14,000,000 sq ft) of mattress per month. During a normal low-water construction season of five months' duration, these three plants are capable of revetting approximately 40 miles of bank with a mattress averaging 350 ft wide.

The reinforcing fabric and fastenings used in the articulated mattress construction are made of corrosion-resisting metal. Copper-coated, high-tension steel, or stainless steel wires, each having a breaking strength of 4,000 lb, are used. This fabrication makes the mattress as indestructible as possible in air and water.

Since complete flexibility is not compatible with a concrete product, the necessary articulation produces interstices through which bank fines can be drawn by the current. Since 1948, a less permeable modification of the articulated concrete mattress, a so-called V-type mattress, has been developed. Only small test installations have been made, but during the 1950 construction season a test section of considerable size was constructed using this mattress. The V-type mattress has open areas of 3% as compared to about 8% in the conventional mattress.

Asphaltic Mixes.—Experiments with nonreinforced asphaltic mixtures are now being made in the form of plastic masses or blocks. For mass placement, the heated mixture is placed in bottom dumpbarges, towed to the site, and released. The plastic mass spreads and congeals to cover the subaqueous slope. When used in the form of blocks, the asphalt mix is cast in water-cooled forms at the site and subsequently released through wells in the barge to cover the underwater slope. This method has not been very successful for new construction, but is usually effective for repair of damaged work, especially in the less turbulent reaches of the lower river.

Bank Pavements.—After a mattress is in place, the graded bank above the water surface is paved to prevent erosion by river currents, which would result in bank instability and consequent loss of the subaqueous mattress.

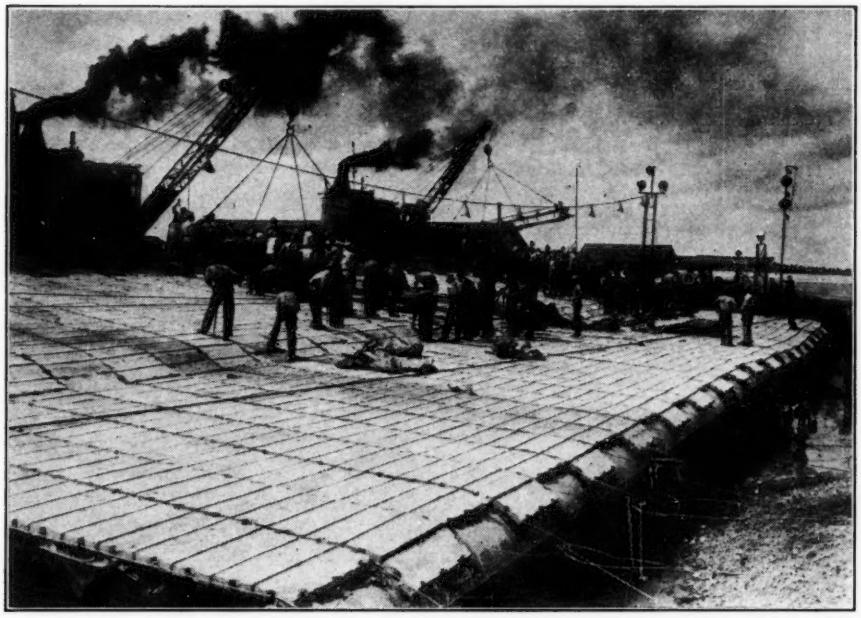

FIG. 2.—CONSTRUCTION PLANT FOR PLACEMENT OF ARTICULATED CONCRETE MATTRESS

Bank pavements of the earlier revetments were generally constructed with the same material as the mattress but experience with brush or fascines and wire netting proved that, when subjected to alternate wetting and drying, the wood soon decayed and the metal parts corroded rapidly. Consequently, stone was adopted as the standard material for bank paving.

Riprap on a 4-in. gravel blanket is considered the most effective pavement yet constructed but, because of the local unavailability of stone, it is rarely used below Memphis. A 10-in. riprap paving can adjust itself faithfully to irregularities in the slope; and it can reform and continue to give protection in the event of minor bank subsidence and sloughing. A pavement that cannot

accommodate such settlements fails locally and requires costly maintenance.

In an attempt to find durable substitutes for riprap, pavements of monolithic concrete, articulated concrete, asphalt, and manufactured blocks have been constructed with varying degrees of success. Of these types only the articulated concrete and noncompacted asphalt pavements remain in general use.

The articulated concrete pavement is identical to the mattresses of the same material but differs in the detail of placement. It is placed on a 4-in. gravel blanket that permits relatively free drainage of ground water but retains the bank fines. Although the articulated concrete bank paving is relatively simple to place, it is comparatively expensive. Therefore, its use is generally limited to connections between the subaqueous mattress and other types of paving. It is also used extensively at the upper and lower ends of revetments, as shown in Fig. 3(*a*), where flexibility is especially desirable to cope with flanking action.

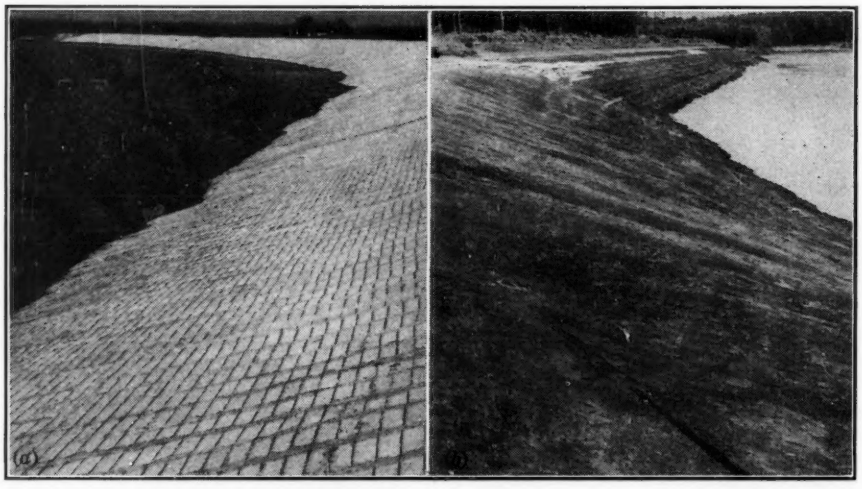

FIG. 3.—UPPER BANK PAVING

In 1945 the porous asphalt pavement (which is in general use below Memphis) was developed. The uncompacted asphalt mass (see Fig. 3(*b*)) is placed on the prepared bank to a minimum thickness of 5 in. It consists of a heated mixture of about 94% bar run sand and gravel, and 6% asphaltic cement. With ordinary bar run sand the porosity of the pavement is about the same as that of loose sand. The degree of porosity, however, can be increased by the addition of a small quantity of pea gravel in the mix. The relatively free-draining feature of the uncompacted asphalt makes it superior to either a monolithic concrete or compacted asphalt pavement.

Pavements composed of ordinary concrete blocks or tetrahedral-shaped blocks show little, if any, advantage over stone. In addition, their high initial cost prohibits general use.

Dikes, Groins, and Retards

Dikes, groins, and retards are intermittent structures that may be permeable or impermeable, according to the function performed and the materials of which they are constructed. Pile dikes and triangular-framed retards are permeable, whereas groins are impermeable. In the past these structures have been used on the Mississippi River below Cairo, mainly as contraction works and as a method of closing secondary channels. Because of the excessive depths and the large amounts of drift present during rising stages, only limited use has been made of pile dikes as bank protection on the Lower Mississippi River. On the Red and Arkansas rivers, however, pile dikes have been used extensively for bank protection with considerable success. A limited use has also been made of retards, groins, and stone dikes on these rivers.

In the plan of stabilization adopted by the Commission, pile dikes and retards are used independently or combined: First, as bank protection works in concave bends; second, as flank protection when a revetment is terminated in an exposed flank; third, to control flow in secondary channels; and, fourth, to deflect or train the channel into a more favorable alinement. Groins may be used for the same purposes, but, because of comparatively higher construction costs, their use is not always justifiable.

As bank protection structures, dikes and groins are designed to defend the banks by holding destructive currents well offshore, but the manner in which this is accomplished differs with the type of the structure. The success of permeable types depends on their ability to trap material moving as bed load or in suspension. The impermeable types fend off current without dependence on accretionary deposits. As in the layout for revetment, the dike system should extend the entire length of the concave bend. When constructed, the outboard ends of the dikes should lie in a smooth curve to minimize turbulent flow, and should extend at least to, and preferably past, the thalweg of the river.

Dikes are used at the lower end of revetments to prevent loss of the revetment by flanking and to provide a directive into the crossing below. The ends of the dikes should lie along a curve of a sharper radius than that obtaining in the bend immediately above. When used to control the flow in secondary channels, the dikes are usually placed at the lower end of the channel, thus trapping the bed load entering the channel through the upper end. Dikes are used to train the river into a more favorable alinement in locations in which it is shallow and has a tendency to meander. Dikes designed to promote growth or downstream migration of bars are examples of this type of construction.

Pile Dikes.—The first pile dike constructed on the Mississippi River consisted of a double row of single piles with the tops pulled together and wired, and the structure wattled with brush. No foundation mattress was provided. This construction proved too light and the dikes were gradually strengthened, the wattling was eliminated, and a mattress was provided along the axis of the dike at the bottom of the river. The common pile dike as shown in Fig. 4, consists of two or more, up to a maximum of seven, rows of pile clumps, three piles constituting a clump. The rows are spaced approximately 5 ft apart,

with pile stringers placed between each row. Clumps are spaced from 15 ft to 20 ft apart depending on the number of rows in the dike. Piles and stringers are secured with several turns of $\frac{3}{8}$-in. galvanized wire strand fastened with boat spikes. The pile penetration varies from 20 ft to 30 ft below the river bed. Each dike is constructed on a woven willow or lumber mattress, as shown in Fig. 5, extending from the water's edge from 45 ft to 75 ft beyond the channelward end of the dike proper. Mattress widths vary from 77 ft to 100 ft. The mattress is ballasted with 15 lb of stone per sq ft and an additional 500 lb of stone per row, per lin ft, are placed in the dike line to fill holes torn in the mattress by pile driving.

The crest elevation of the pile dike is usually set at mid-bank stage, which is from 15 ft to 17 ft above the low-water plane. There are two reasons for choosing this elevation. First, pile lengths would become excessive if the top

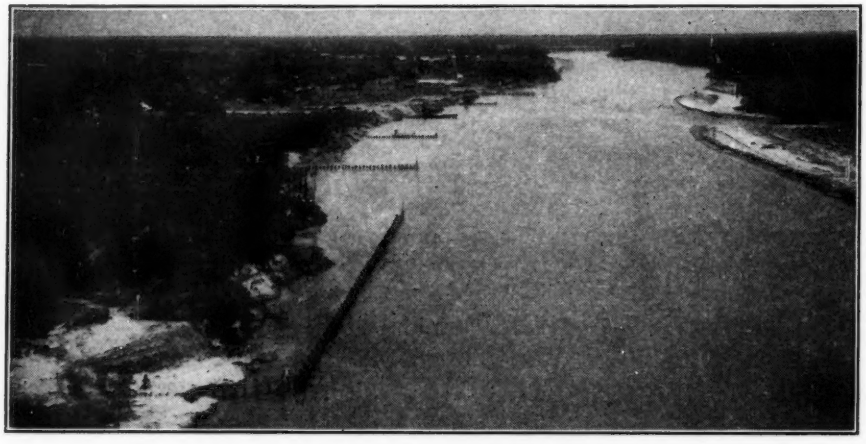

FIG. 4.—PILE DIKE SYSTEMS

of the dike were raised substantially above this elevation, and, second, the most severe current impingement on the bank in a bend usually occurs between the low and mid-bank stages. After the latter stage is exceeded, the river has inundated the bar opposite the bend and the flow becomes more or less axial.

Bank protection dikes are spaced from $1\frac{1}{2}$ times to $2\frac{1}{2}$ times the length of the upstream dike, depending on the radius of curvature of the bend and the angle and intensity of the current attack. The upstream dike of a system is inclined downstream at a small angle with the bank and extends to the rectified channel line. This upstream structure is designed to turn the current slightly offshore. The remaining dikes in a system are placed normal to the bank line or angled approximately 15° downstream from normal.

When used to control flow in secondary channels, the height of the dike is raised, where feasible, to the top of bank elevation and the dike is extended completely across the channel.

Dikes placed on the convex side of the river to promote bar growth are spaced about $2\frac{1}{2}$ times the length of the upstream dike up to a dike length of 1,000 ft. For longer dikes, the relation between length of dike and spacing is less. All dikes are normally angled slightly downstream.

After the mattress has been constructed and pile driving has begun, the bank head is graded to a stable slope. The width of the bank head is equal to the width of the mattress. The graded slope is then dressed and paved with a 10-in. stone pavement. When necessary, a gravel blanket is placed under the stone to prevent loss of bank fines. The dike is extended landward to the top

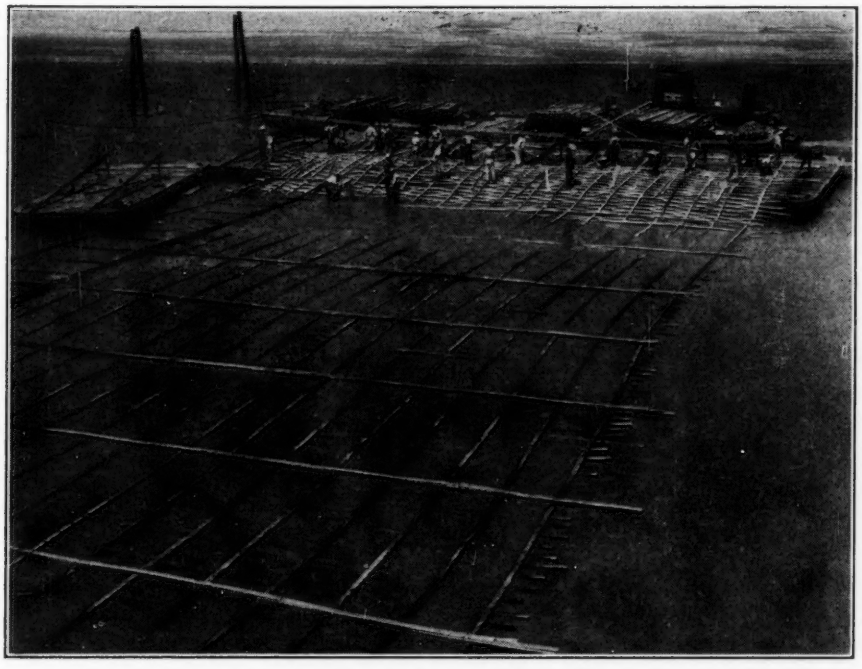

FIG. 5.—LUMBER MATTRESS UNDER CONSTRUCTION

of the graded slope by a root section of single piles spaced 6 ft apart. Root piles are staggered in two rows in order to permit the placement of stringers.

Abatis Retard.—The abatis retard, constructed first in 1898, is a forerunner of the triangular-framed retard, which consists of a triangular prism of lumber frames with a covering of screen poles on the upstream face. A willow pole mattress 26 ft wide is an integral part of the structure. The retard is constructed on barges in lengths up to 98 ft. In order to facilitate sinking, ballast stone in an amount of 500 lb per lin ft is placed on the upstream 8 ft of the mattress. After assembling a section on a barge and ballasting, anchors leading upstream are attached and the section is sunk to the river bed as shown

in Fig. 6. By placing multiple sections, the retard can be made to extend any desired length. When in place, the tips of the screen poles are about 20 ft above the river bed. Unless the retard is placed as an extension to pile dikes, the bank is graded and paved, and a pile root is constructed in the same manner as for the pile clump dike. Retards are usually built in pairs normal to the current, the individual retards being from 200 ft to 500 ft apart and the pairs, from 1,000 ft to 1,500 ft apart.

Groins.—Groins are in the experimental stage on the Lower Mississippi River, although several rock groin installations have been successful on the Arkansas and Red rivers (Fig. 7). On the Lower Mississippi River groins have commonly been constructed with mass asphalt. Experiments with three types have been made: The first type has a uniform cross section extending from the bank to the deep water; the second has a level crown elevation; and the third type is merely a flexible blanket about 200 ft wide, extending from the top of the bank to the thalweg. In an experiment with the latter type, a series

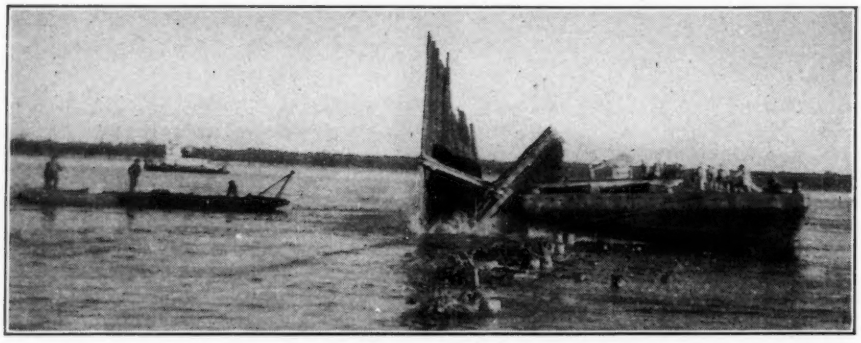

FIG. 6.—LAUNCHING OF TRIANGULAR-FRAMED RETARD

of blankets were placed in a concave bend and, as the current scoured out the sand between the blankets (the blankets being more resistant to scour), a relatively superior crest elevation to the intervening area was maintained, thus effectively forming groins of the first type with considerably less material. Although results have not been evaluated, considerable weakness has been indicated at the shore connections that are vulnerable to destruction by eddy action both from upstream and downstream.

Stone and asphalt dikes serve the same function as groins but differ in construction detail. The crown is kept at a constant elevation, usually equal to the top of the bank. Excessive quantities of materials are required for these structures and the consequent high cost prohibits their use except in rare cases.

PROBLEM OF BANK STABILIZATION

As of January, 1950, there were approximately 170 miles of stabilized banks on the Lower Mississippi River between Cairo and Baton Rouge, La. Approximately 255 miles of caving bank remained to be stabilized. The greater

part of this mileage will be protected by articulated concrete revetment and a lesser part by dikes, retards, and groins.

Causes of Failure.—The design of articulated concrete mattresses is being modified from time to time as improvements are evolved. Although the primary purpose of a revetment is to stabilize the banks, a revetment is not a retaining wall; hence, effectiveness is lost whenever the bank loses its equilibrium. A bank may become unstable, after revetting, from numerous causes. Excessive scour that undermines the revetment along the toe may steepen the slope to such an extent that it is no longer stable and the bank sloughs, moving the revetment with it. Intensive and prolonged attack may disarrange parts

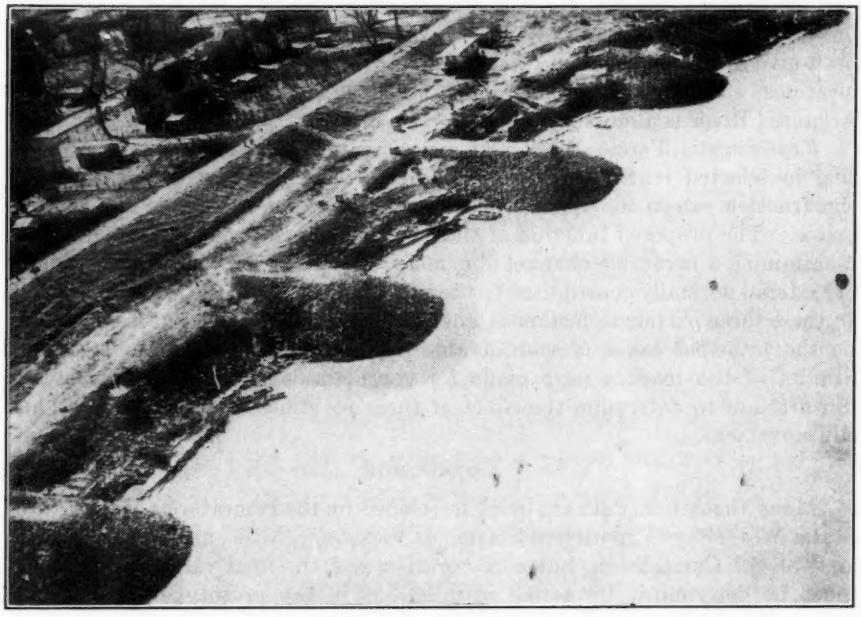

FIG. 7.—STONE GROINS

of the mattress and leave the bank vulnerable to attack, or the bank may slide because of hydrostatic pressures or an inherently unstable condition.

There is much speculation as to whether the weight of the revetment is sufficient to prevent disarrangement by river currents with velocities in excess of 5 ft per sec. It has been suggested that vibration of the slabs would destroy the integrity of the revetment, in time, and thus subject the bank to slides by scour. A theoretical investigation of the extent and consequences of such action is being made in the laboratory. Because of the great depths, swift currents, and opaqueness of the water, determinations from subaqueous examinations of mattress work by divers have not been entirely satisfactory.

Dikes and other timber structures are ordinarily satisfactory when material deposits from within three to four years. Until such deposits form, the dikes

are subject to destruction by drift, ice, and vibration. If no accretion forms, the dikes are subjected to deterioration by decay. Experience indicates that no accretionary deposit is more permanent than the structure that produces it; therefore, retards and dikes are constructed principally of creosoted timbers to give longer life.

Many of the recorded failures of revetments and dikes on the lower river cannot be ascribed to the material used or to the type of structure built but to the inability to complete the works as conditions required. Many losses result from the flanking action of river currents when the demand for work at other critical locations makes it impossible to complete the work to the full extent of the caving bank. Most of the critical situations will be ameliorated and the work contemplated by the stabilization project can then be vigorously prosecuted in a systematic manner. Although so far first consideration has been given to the correction of especially troublesome reaches involving levee locations, stabilization of the reach from Helena, Ark., to the mouth of the Arkansas River is almost completed.

Experimental Work.—Work of an experimental nature has also been progressing in selected reaches. Three revetments were installed during the 1949 construction season to support revetments in the opposite bends immediately below. The proposed function of these supporting revetments, in addition to maintaining a favorable channel alinement, is to reduce, radically, the volume of material normally contributed to the point bars opposite the lower revetment. In these three particular instances, encroachment of the point bar is believed to be the principal cause of considerable destruction to the lower revetment. Studies of the reaches were made for considerable distances upstream and downstream to determine the effect of these revetments on bar building and silt movement.

Conclusion

Many theoretical data are being developed by the laboratories of the United States Waterways Experiment Station at Vicksburg, Miss., and the engineering staff of the Commission, but corroboration and the final value of the theory must be determined by actual installations in the prototype. In cases of uncertainty, especially troublesome reaches of the river are chosen to serve as pilot models for testing new ideas and improved structures. Thus, the stabiliaztion of the Lower Mississippi River is following a plan based on both theory and experience, especially the latter. The river flow is not being radically interfered with but its lateral movement and, consequently, the material contributed to the stream by bank erosion are being controlled in order to (1) preserve the benefits of lower flood heights previously obtained by the cutoff program, (2) direct the river energy in deepening the channel for navigation, and (3) eliminate the necessity for continually retiring the levees.

Acknowledgment

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